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A Mathematical Study of the Optimal Path in an Intelligent Autonomous Guided Vehicles: A Game Theory Approach

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Abstract

This paper proposes a new model for the optimal area coverage of machines in the production line by applying a single Autonomous Guided Vehicle (AGV) to minimize both transfer costs and the number of breakpoints of the AGV, as well as the equilibrium point. One of the unique advantages of the area coverage employed in the present study is that it minimizes transfer costs and breakpoints, making it possible to provide service for several machines simultaneously. The underlying assumption is to specify a path that ensures the coverage of every point in a given workspace at least once. Since a rail AGV is used in this study, the AGV can only traverse horizontal and vertical distances on the production line. The reversal of the AGV path in vertical and horizontal distances implies a kind of failure mode and a break of point in the present paper. The simulation results confirm the feasibility of the proposed method. Using game theory can help the system choose the most appropriate AGV to perform a task in a short time, thereby reducing the overall response time of the system and improving its efficiency. This paper employs a regulated speed policy to avoid conflicts, which can help maximize the efficiency of the system. It is demonstrated through simulation that the strategy improves the flexibility, robustness, and efficiency of the AGV system.

Keywords: Autonomous guided vehicles, Regional coverage, Game theory.

1 | Introduction

Technological innovations in autonomous vehicle-based systems are geared towards achieving greater operational efficiency and flexibility necessary for the further development of modern industries. Before the Industrial Revolution, humans carried out their work using the power of their arms and without any

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automation technology. With the onset of the Industrial Revolution, there was a growing trend in technology and the construction of machines and vehicles that freed humans from repetitive, tedious, and sometimes even dangerous tasks. AGVs are material handling machines used for the transport of pallets (goods and materials) in distribution areas, such as industries, warehouses, cross-docking centers, and container terminals, to optimize productivity and efficiency in material handling tasks. Their specific advantages and benefits include increased flexibility in processes, low labor costs, 24-hour availability (depending on the battery's charging time), and computer integration and management of handling operations [1], [2].

The number of AGVs required for task execution and the existence of an efficient task scheduling and routing system are the main factors that must be examined for the implementation of an AGV system, not only to minimize the time spent but also to avoid collisions and deadlocks [3–5]. Bish et al. [6] defined the primary AGV management functions as follows: 1) dispatching function, which involves selecting and assigning tasks to vehicles, 2) routing function, which entails selecting the specific paths taken by vehicles to reach their destinations, and 3) scheduling function, which determines the arrival and departure times of vehicles at each segment along their prescribed paths to ensure collision-free journeys. In this paper, the focus was on the issue of routing, including the selection of the specific paths taken by AGVs to reach destinations.

There are several indicators for evaluating the routing of AGVs [7]. The primary problem is attenuating the whole travel distance of AGVs, which can not only convey the tasks to the destination as early as possible but also reduce the energy consumption of AGVs. The second is to minimize the breakpoint of AGVs' workload, which can ensure capacity equalization and avoid resource waste. The third is to minimize the predicted delivery time of tasks, which can ensure the stability of the production process and improve production capacity in industrial production. Although the analysis of the routing problems started in the early 80s [8], new approaches related to the minimization of AGV routes in industrial applications have been proposed in recent years [7].

The main problem regarding obtaining an AGV control for satisfactory performance is the determination of the optimal number of vehicles to attend all tasks on time with a sufficient number of vehicles [5]. Conventional goal-oriented and map-based path planning methods, Artificial Potential Field (APF), cellular decomposition, template-based, sensor-based, neural networks, and fuzzy logic are among various approaches to exhaustive and random coverage path planning [9]. This paper aims to propose a new mathematical model for the area coverage of machines on the production line. It applies a single AGV to minimize both transfer costs and the number of breakpoints. Since a rail AGV is used in this study, the AGV can only traverse horizontal and vertical distances on the production line. The reversal of the AGV path in vertical and horizontal distances indicates the failure mode and breakpoint discussed in this paper.

The main contributions of this paper are summarized as follows: 1) transfer costs and breakpoints are minimized, resulting in a reduction of the total travel distance of the AGV and the objective value. Tasks can be delivered in a shorter period of time, leading to reduced production costs and improved production efficiency and productivity, 2) the area coverage model proposed in this paper can be applied in other manufacturing businesses. The proposed model aims to develop a more efficient framework by considering the advantages and shortcomings of previous studies. The remainder of this paper is organized as follows, and 3) we utilize game theory to optimize these paths. We also extend the proposed methodology to the n-player case ($n \geq 3$) and provide more generalized insights.

The game consists of three elements: the set of participants, strategy space, and the return function. In the AGV scheduling system, we assume that all points are "rational agents," and we can obtain K results after each AGV takes the same task but chooses different paths, with the execution time representing K types of benefits. Since the AGV system treats the optimal solution as the shortest time for transportation, the "return function" is a "negative income function," where a smaller value indicates a better outcome. This paper presents an optimum path selection method that is based on game theory and uses variable speed mode to prevent collisions between AGVs. Compared to the traditional method, in which the system builds the path table first and then chooses the optimal one from all the available paths, the method in this paper costs less

time and has high value in practical application systems. In Section 2, previous studies related to this research are reviewed. In Section 3, mathematical modeling and model hypotheses are discussed comprehensively.

The AGV is described in detail through an illustration of the manufacturing process and the proposed mathematical model for this problem, and a numerical example is provided. Then, the comprehensive criterion method is applied according to the weights of the objectives to achieve the most accurate optimal solution. In Section 4, the results are analyzed, and the conclusions are discussed. In Section 5, future research directions and conclusions are presented.

2 | Literature Review

Automatic Guided Vehicles (AGVs) are material-handling machines traveling on a network route [10–12] that can be interfaced with various other production and storage machines [13]. The AGV vehicle is a guided vehicle or mobile robot and is guided by wire markers, tape, optometry, or laser. An efficient AGV scheduling will increase productivity and reduce the delivery cost [14].

Nowadays, many AGVs are employed to carry out repeated transport tasks in many manufacturing and warehouse industries. Their intensive application is influenced by many vital factors of apparatus expense, vehicle maneuverability, energy potency, and configuration flexibility, particularly in an exceedingly large-scale AGV system. Intelligent transportation systems square won't increase productivity and cut back the transportation costs in producing businesses. The first AGV in the world was developed by Bart Electric company in 1953, and it was mainly used to control the grocery store [15]. A min-max goal programming was suggested to get optimal compromise systems. The first kind of stability set corresponding to the optimal system design was defined and resolved [16]. A vendor selection problem was introduced with fuzzy parameters.

The maximum and minimum values for the constraints transformed them into two classical linear programming problems [17]. Edalatpanah et al. [18] studied cooperative continuous static games characterized by fuzzy cost functions that are piecewise quadratic. It introduced an effective approximation technique, specifically the close interval approximation for piecewise quadratic fuzzy numbers. They used the weighted Tchebychff method to derive an optimal compromise solution and established the corresponding stability set of the first kind. Performing partial repairs returns the production machine's wear level to its previous state, while complete repairs return it to its initial condition. The possibility of partial maintenance repairs was limited, and reaching the maximum allowable level necessitated unavoidable complete repairs. Additionally, the quality of the final product depends on the production machine's wear and tear level; thus, as the level of machine wear increases, the likelihood of producing low-quality products also increases [19].

A multi-objective minimum cost flow with possibilities objective function coefficient was used in the goal programming approach. The parametric study under the concept of alpha is a possibly optimal compromise solution [20]. The flow shop scheduling problem has been studied in a fuzzy environment. The concept of the close interval approximation of piecewise quadratic fuzzy numbers has been applied to find a job permutation that minimizes the makespan. This operation averts the information missing from fuzzy processing times. A comparative study has been achieved. In addition, the proposed method can be applied to different types of fuzzy numbers and in uncertain environments [21].

An effective (and often extensive) traffic surveillance and monitoring system was a prerequisite for any intelligent traffic control system to keep track of prevailing conditions across the network. A wide scope of various sensors was introduced in, on, or more the street for this argument and to acquire the important geological and crucial time inclusion [22]. Mohammed [23] proposed a multi-agent-based solution to support collaboration between logistics objects within the context of smart logistics. In contrast with existing works, the structure of each agent includes two concurrent belief-desire-intension structures for individual and collective logistics, respectively. Until the mid-seventeenth century, AGV systems grew rapidly, and there were more than 100,000 AGVs in the nineteenth century [24].

AGVs are commonly used for material transportation in distribution, warehousing, and factory systems. Among automated transportation systems, AGV systems can be integrated with other systems, are more economical and flexible in capacity and route, and have environmental benefits that make them of particular importance [25–27]. AGVs are battery-powered and manned machines that can be programmed to select routes and positions. They also can respond quickly to changes in transmission patterns and can be integrated into automated manufacturing systems. The AGV option is more durable than other material handling systems and can increase productivity due to lower manpower costs and improvement of system flexibility [28]. AGV systems are robots that require the cooperation of all types of AGVs to perform material handling tasks. Routing planning is an important issue in AGV systems that aims to minimize the time traveled or the travel distance [29]. The main focus of researchers is on the route planning of AGV and improving system performance [30], [31]. AGV scheduling can be divided into online and offline scheduling. In some research, important factors, such as limited input and output, buffer capacity, random arrival, preparation of work packs, maximum time, etc., are taken into account when adapting the types of algorithms to solve the model. A multiple-decision support system to weigh each criterion for AGV selection was introduced [28]. In fact, they ranked the options to select the appropriate AGV using the fuzzy TOPSIS method.

A rational process for selecting the appropriate AGV for the production environment according to its applications was proposed [5]. This process was based on the Preference Selection Index (PSI), which evaluates and ranks the options, and then the results of this process were compared with the TOPSIS method. A new approach to solve the problem of heterogeneous AGV routing by considering energy consumption has been proposed [32]. The PSO (particle swarm optimization) algorithm was used to solve the problem. It was assumed that the shorter the distance, the better the planning route, while in previous studies, the goal was only to minimize the distance. A distributed routing method under motion delay disturbance was proposed, and some unexpected disturbances such as motion delay, sudden transfer requests, and increased total time were considered. The optimal path on an Autonomous Guided Vehicle (AGV) routing problem network considering triple criteria of time, cost, and capacity was studied [10]. This paper aimed to determine an optimal route for a single AGV on a production line containing several machines so that it covers all machines by considering two criteria for minimizing transfer costs and breakpoints.

A district coverage operation as a route planning program requiring a robot to cover every part of the workspace was employed [24]. A new solution to the problem of optimal regional coverage based on a Genetic Algorithm (GA) to obtain the best path has been proposed [9]. The simulation results of their proposed model confirm the feasibility of the method. A new Mimetic Algorithm (MA) as a GA that combines global and local search was proposed to optimize the partitioning problem of tandem AGV systems. The objective is to minimize the maximum AGVs' workload to balance the workload among all the zones and hence avoid the presence of bottlenecks [26]. A harmony search-based mimetic optimization model was proposed to handle the production and transportation scheduling problem in a Make-to-Order (MTO) supply chain. Certain heuristic procedures were proposed to convert the investigated problem into an order assignment problem [25].

A computer-integrated manufacturing system was designed to identify an optimal path in an AGV routing problem network, a special case for Vehicle Routing Problem (VRP) considering triple criteria of time, cost, and capability in decision-making simultaneously [10]. A comparative study between three approaches of the Dijkstra algorithm, GA, and a heuristic method was made to handle routing, assignment, and scheduling problems of containers to AGVs [32]. A new approach to planning the facility layout of the investigated AGV-based modular prefabricated manufacturing system was proposed [33]. An optimization method for the size arrangement of the workstation area and the storage area was developed to minimize production time and maximize workstation utilization. A simulation of a genetic sorting algorithm is proposed to solve the model.

A heuristic method was utilized to guide the placement, reshuffle, and retrieval of the modular prefabricated products in the storage area. A multi-objective mathematical model of AGV scheduling and an improved

Harmony Search (HS) algorithm was proposed by considering rate (HMCR) parameters and implementing a neighborhood search strategy for the best harmony in Harmony Memory (HM) to reduce the total travel distance of AGVs, the objective value, and the production cost [34]. A new method based on the Inference Search (IS) algorithm was developed for optimizing scheduling and minimizing mean tardiness in identical parallel joint robots [35]. Results indicated that the proposed method, unlike Genetic Algorithms (GA), Taboo Search (TS) algorithms, and Hybrid Intelligent Solution System (HISS), was scalable, and it optimized the parameters of mean tardiness and system solution time. A multi-objective mathematical model of AGV scheduling with three objectives, i.e., the total travel distance of AGVs, the standard deviation of AGVs' workload, and the standard deviation of the difference between the latest delivery time and the predicted time of tasks, was used. Then, an improved HS algorithm was proposed for the best harmony in HM [7]. The IS algorithm was proposed as a new model for scheduling and minimizing mean tardiness in identical parallel joint robots. Unlike GA, TS algorithms, and HISSs, the proposed model was scalable and more successful in optimizing the parameters of mean tardiness and system solution time [36]. A novel parallel algorithm for multi-AGV warehousing systems was employed for task assignment, path planning, and vehicle navigation [37]. Various practical simulations were conducted to examine the efficiency and robustness of the new algorithm. Game theory has been used in recent years to achieve balance in marketing and strategic management [37].

According to the review of past literature, we find that the combination of mathematical models with game theory, in addition to reducing costs and commuting for machines, should also consider equilibrium, which is less visible in previous studies. This literature review indicates that the use of game theory for analyzing AGVs is still in its early stages but has good potential for addressing the mentioned challenges. From 2020 to 2024, 25 papers discussed aspects of AGVs using game theory, namely interaction with other systems, security, and transportation acceptance and trust. Despite addressing aspects related to AGVs, these studies were not published in venues commonly chosen by the cost and equilibrium community. Furthermore, the majority of the papers were directed toward cost and equilibrium.

3 | Methodology: Problem Definition and Mathematical Model

The area coverage in the present paper implies that the machines are assumed to be located in a specific area to be serviced by a single AGV. It is sufficient for the AGV to visit at least one point of a machine to be regarded as the server of that machine. In fact, machines are considered as areas and zones here. If machines are to be considered as points, modeling would resemble a traveling vendor problem to find the optimal path that starts at the desired point and ends at that point. Modeling for such problems is not difficult when the machines are assumed to be points. Since the machines are considered to be areas in the present study, modeling must be done differently. Area coverage modeling in the present study was inspired by point coverage with a few changes. The AGV starts providing services from one point of a machine (no starting points are considered for the model).

The solution of the model yields the optimal path, and each point in the optimal path can be considered as the starting point. After completing a closed path, the AGV returns to the same point of the machine; in this case, it is sufficient for the AGV to visit at least one point of the rectangular area to cover the path. In area coverage, an AGV may cover two or more machines simultaneously (at one point), whereas in point coverage, this is not possible. This is one of the major benefits of area coverage, which can save a significant amount of time, energy, and money in factories. *Fig. 1* clearly illustrates this. *Fig. 2* shows an image of a rail AGV.

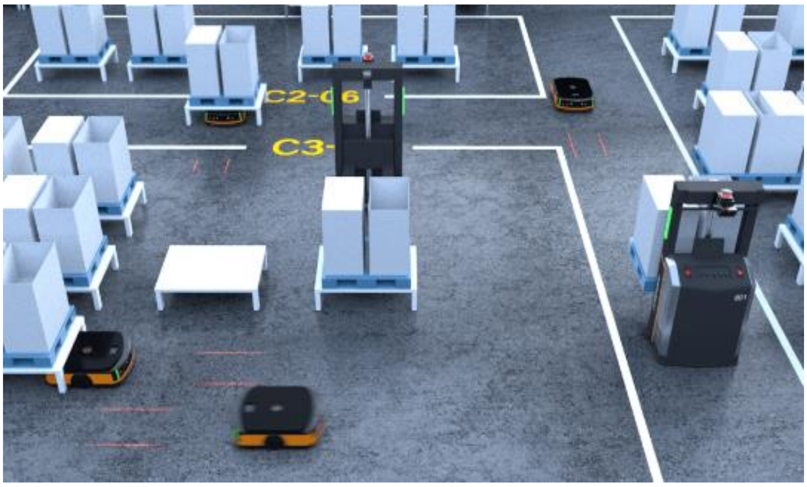

Fig. 1. Area coverage of AGV.

Fig. 2. A rail AGV.

Fig. 3 shows several machines and an area for holding AGVs, and the machines are scattered in a rectangular area throughout the factory environment.

Fig. 3. Regional coverage of AGV in which machines have been considered as the areas (blue and yellow lines).

In *Fig. 4*, every 10 machines is considered as a rectangle (area). The blue route covers "one point of cars 1, 3 and 5" and "2 points of cars 2 and 4" and aims to determine the number of these routes so that a circle is formed and all machines are covered. Failure occurs when the end of this blue path changes its direction vertically. The two yellow points in *Fig. 5* are the breakpoints.

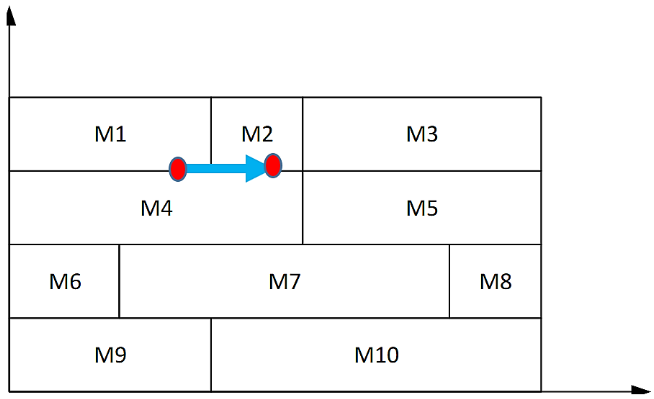

Fig. 4. Top preview of a factory with 10 machines with a single AGV.

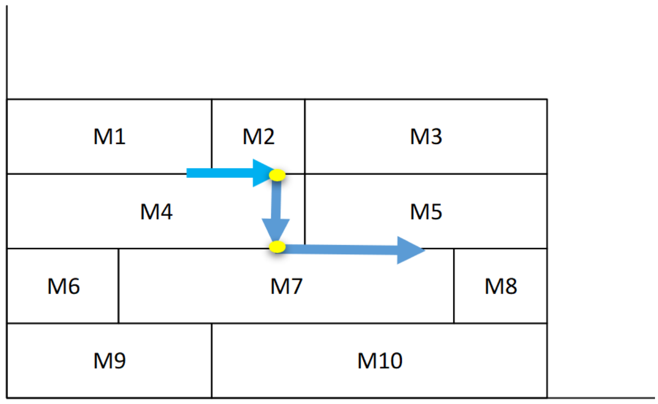

Fig. 5. Top preview of top preview of a factory with 10 machines with a single AGV and display of breakpoint.

Based on the above steps, the establishment of the decision-making model is shown in *Fig. 6*.

Algorithm 1 starts with the randomly generated location and "walks" to an equilibrium if it exists. The idea of the local search algorithm is as follows. From the original random location, the algorithm selects the firm that is most motivated to move from its neighborhood; that is, the algorithm compares all firms' payoff at the original location with the payoff at the neighbor.

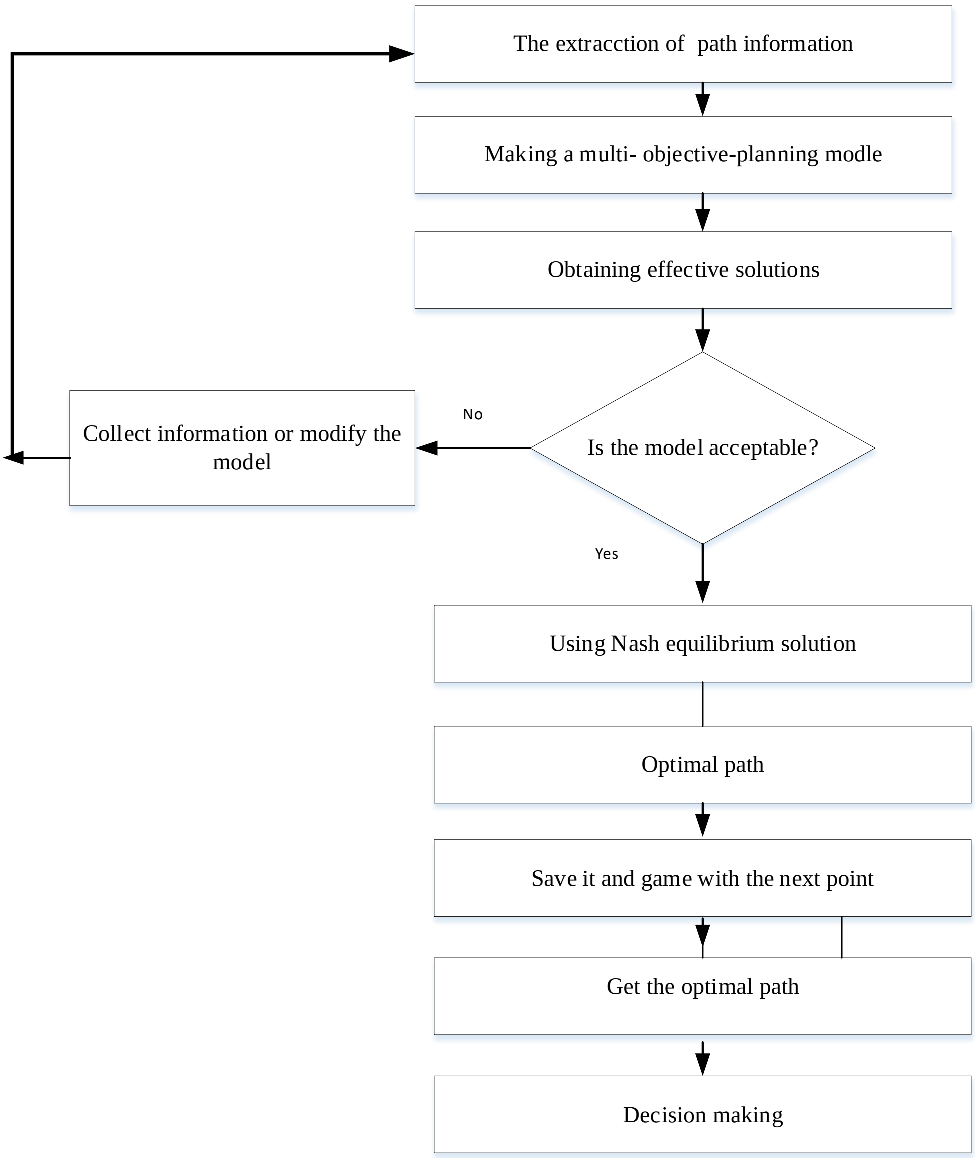

Fig. 6. Process required to introduce model (proposed algorithm) [38].

3.1 | Main Assumptions

The model of this study has been proposed on the basis of some assumptions that seem necessary to be specified to run the model in a real-world situation. These assumptions are presented here:

I. Machines are considered as areas and zones. (as a rectangle).

II. If at least one point of the device is located in the AGV path, that device is covered by the AGV.

III. The breaking point is defined as follows: when a path direction changes its direction in a loop, a failure occurs.

IV. The rules of play are known to all the players.

V. There is a conflict of interest between the players.

VI. All players act rationally and intelligently.

In order to facilitate the understanding of the mathematical model, the sets, parameters, and decision variables are introduced in this section.

Indexes

i: index along the axis x $i = 1,2, \dots, X$.

j: index along the axis y $j = 1,2, \dots, Y$.

Parameters

$C_{iji'j'}$: transfer cost from point (i, j) to point (i', j').

$d_{iji'j'}$: distance from point (i, j) to point (i', j').

$x_{iji'j'}$: if there is a direct connection from (i, j) to $(i', j') = 1$, otherwise 0.

M: total machines.

$d_{iji'j'}$: security level (disagreement utility) for player $iji'j'$.

Variables

$Z_{iji'j'}$: if AGV moves (i, j) to $(i', j') = 1$, otherwise=0.

$f_{iji'j'}$: the payoff for player $iji'j'$.

3.2 | Mathematical Model

$$\text{Min: } Z_1 = \{\sum_{i}\sum_{j}\sum_{i'}\sum_{j'} C_{iji'j'} * d_{iji'j'} * Z_{iji'j'}, \sum_{i}\sum_{j}\sum_{i' \neq i}\sum_{j' \neq j} Z_{ijij'} * Z_{ij'i'j'} + \sum_{i}\sum_{j}\sum_{i' \neq i}\sum_{j' \neq j} Z_{iji'j} * Z_{i'ji'j'}\}. \tag{1}$$

$$\max Z_2 : \prod_{iji'j'=1}^{M} \left(f_{iji'j'} - d_{iji'j'}\right).$$

s.t.

$$f_{iji'j'} \geq d_{iji'j'}, \quad \text{for all } iji'j' \in \{1, \dots, M\}.$$

$$\sum_{i'}\sum_{j'} Z_{iji'j'} \leq 1, \quad \text{for all } i, j.$$

$$\sum_{i}\sum_{j} Z_{iji'j'} \leq 1, \quad \text{for all } i', j'. \tag{5}$$

$$\sum_{i'}\sum_{j'} Z_{iji'j'} * x_{iji'j'} \geq 1, \quad \text{for all } i, j \in M. \tag{6}$$

$$Z_{iji'j'} \leq x_{iji'j'}, \quad \text{for all } i, j, i', j'. \tag{7}$$

$$\sum_{i'}\sum_{j'} Z_{iji'j'} = \sum_{i'}\sum_{j'} Z_{i'j'ij}, \quad \text{for all } i, j. \tag{8}$$

$$Z_{iji'j'} + Z_{i'j'ij} \leq 1, \quad \text{for all } i, j, i', j'. \tag{9}$$

$$\sum_{i}\sum_{i'} Z_{iji'j'} \geq 1, \quad \text{for all } 1 < j < X - 1, \quad j' = j + 1. \tag{10}$$

$$\sum_{j}\sum_{j'} Z_{iji'j'} \geq 1, \quad \text{for all } 1 < i < Y - 1, \quad i' = i + 1. \tag{11}$$

$$Z_{iji'j'} \quad \text{binary}. \tag{12}$$

Eq (1) is the first objective function that calculates the amount of the transfer cost. *Eq (2)* is the second objective function, which expresses the number of failure points. *Constraint (3)* states that the payoff of each player (points) must be greater than the corresponding security level. *Constraint (4)* states that the movement can be made from one point to another point (maximum of one output from one point). *Constraint (5)* states the number of points that can be reached to a certain point is maximally one point (Maximum of one input to each point). *Constraint (6)* states that the AGV must pass through at least one point in each machine. *Constraint (7)* states that it can be possible to go from one point to the next one only if there is a path. *Constraint (8)* states that the number of inputs to a point is equal to the number of outputs from that point. *Constraint (9)* between two adjacent points, there is at most one path in the loop (if there is a path in the loop). *Constraints (10)* and *(11)* express the limitation of the single-loop AGV pathway.

The intersection of each side of a rectangle with the x and y axes is denoted by the set i and j, respectively.

3.3 | Numerical Example

Suppose there are 10 machines, each of which is shown as a rectangle. The AGV path is to be defined (optimally) so that at least one corner point of each rectangle (rectangle) is covered. There are also two objectives:

I. Minimizing the transfer costs and the number of breakpoints.

II. Maximum the number of payoffs.

The cost of moving from one point to another is also taken fixed at ($C_{ij} = 25$) and the distance of i points from each other as well as the distance of j points from each other equal 2 meters (*Fig. 7*).

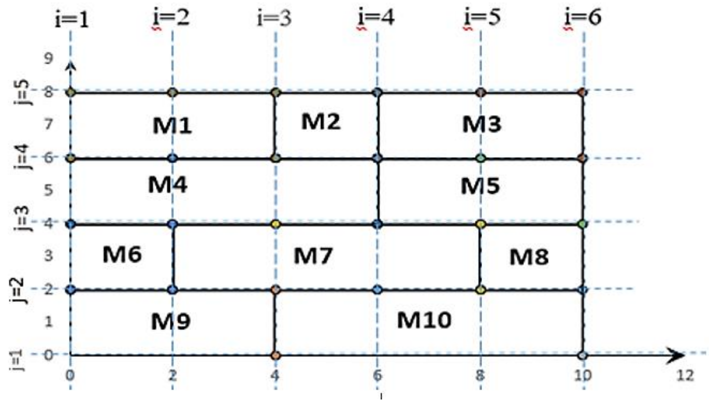

Fig. 7. Top preview of the machines in the factory with the display of the length and width of the machines.

If the first objective function is put in priority 1, the problem is solved, and the optimal answer is equal to:

$Z_1 = 1200$, $Z_2 = 11$, $Z_{1323} = 1$, $Z_{2322} = 1$, $Z_{2232} = 1$, $Z_{3242} = 1$, $Z_{4252} = 1$, $Z_{5253} = 1$, $Z_{5343} = 1$, $Z_{4344} = 1$, $Z_{4434} = 1$, $Z_{3424} = 1$, $Z_{2414} = 1$, $Z_{1413} = 1$.

Assuming the starting point is (1, 3) (which does not influence the solution), and Z_{1323} equals one, there exists a path from (1, 3) to (2, 3) (shown as the yellow path in *Fig. 7*). Since Z_{2322} equals one, a path exists from (2, 3) to (2, 2) (depicted by the blue path in *Fig. 8*). The first failure occurs here because the direction changes from horizontal to vertical. Other variables in the optimal solution indicate the path shown in *Fig. 8*.

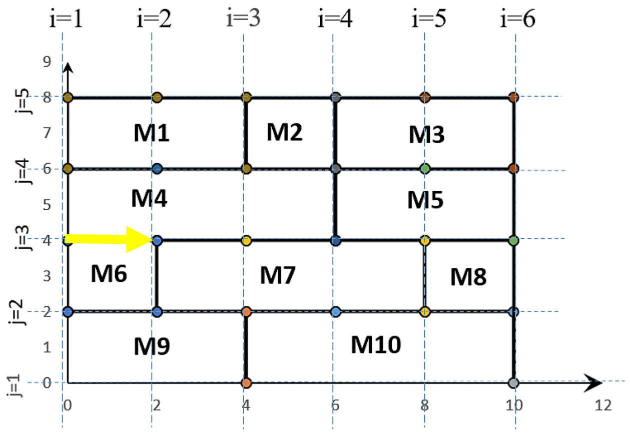

Fig. 8. Display of the yellow path according to $Z_{1323} = 1$.

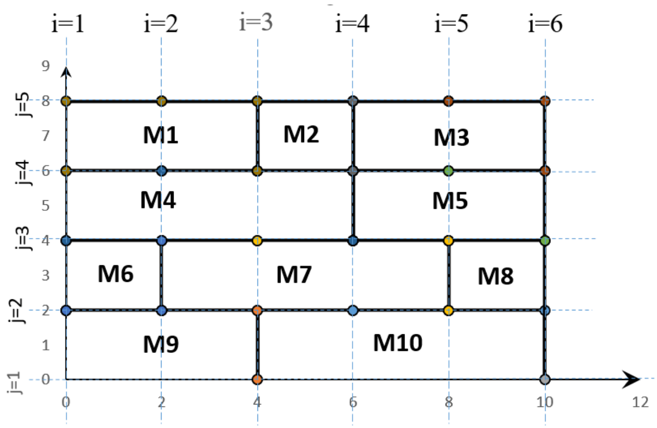

Fig. 9. Display of the blue path according to $Z_{2322} = 1$.

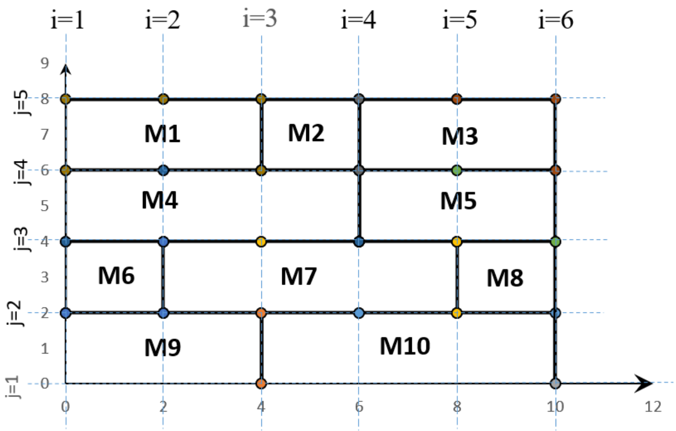

Fig. 10. The optimal loop of the problem regarding the first objective function as the priority 1.

If the second objective function is put in priority 1, the problem is solved, and the optimal answer is equal to:

$Z_1 = 1900$, $Z_2 = 15.275$, $Z_{1312} = 1$, $Z_{1222} = 1$, $Z_{2232} = 1$, $Z_{3242} = 1$, $Z_{4252} = 1$, $Z_{5262} = 1$, $Z_{6263} = 1$, $Z_{6364} = 1$, $Z_{6454} = 1$, $Z_{5444} = 1$, $Z_{4434} = 1$, $Z_{3424} = 1$, $Z_{2414} = 1$, $Z_{1413} = 1$.

Regarding the previous explanation, the optimal AGV path is shown in *Fig. 11*.

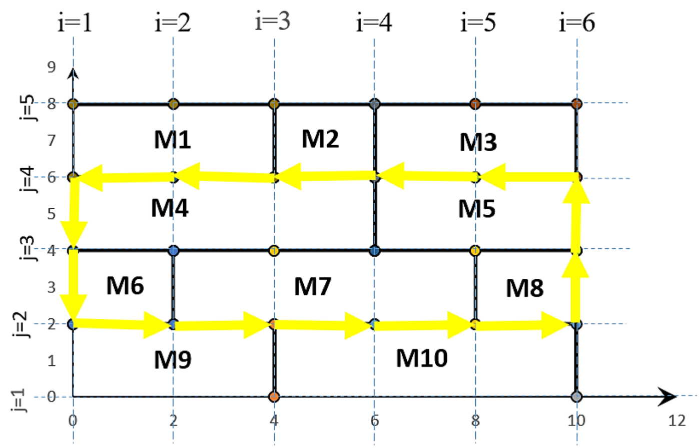

Fig. 11. Optimal problem loop with respect to the second objective function as priority 2.

4 | Results

This study proposes a new approach to assigning a randomly available AGV to a container and then selecting a randomly available path for the AGV routing.

I. Considering a task respecting precedence constraints.

II. Considering a random available AGV.

III. Considering a random path to go from the current position of the AGV to the initial position of the container.

IV. Estimating a random path to transport the container from its initial position to its final position.

V. Repetition of steps 1 to 4 for the N tasks.

Computing the objective function:

I. Generating the initial population randomly.

II. Applying the GA with its operator's selection, crossover, and mutation.

III. Correcting the errors after crossover and mutation by computing the shortest path for d.

IV. Stopping the algorithm when the solution does not reveal significant evaluations after a certain number of generations, a computer with 2GO of RAM memory, a language application of C++, and 1.5GHz processor speed is used in the present study.

The different numbers of tasks and AGVs are applied. The GA parameters include the probability of individuals selected from every population for crossing, which is 0.7, and the probability of individuals selected for mutation, which is 0.1. For each number of tasks (20, 40, and 60), an average of ten running tests are used, and then the objective function value variation with generation number variation is computed. For each approach, the tests are applied for 20 tasks and 4 AGVs, 40 tasks and 6 AGVs, and for 60 tasks and 8 AGVs. After this step, we will compare the results obtained from the three approaches. The port is modeled as a graph having 10x10 km2 of surface and 10 nodes. (Matrix in Annex) The best solution obtained in different populations in IS, genetic, TS, and HISS algorithms in the 8×100 size is shown in *Fig. 12*.

It should be noted that the TS algorithm has been more successful than the GA algorithm with respect to minimizing the mean tardiness in 100 runs. Although GA and TS have similar results, TS produces the best solution compared to GA. In comparison, it can be argued that the IS algorithm was notably more successful than the GA, TS, and HISS algorithms. According to *Fig. 13* and *Fig. 14*, it can be argued that the amount of the produced gap in scheduling is directly related to the total fitness of the scheduling. The reason and

justification for the steep slopes in the produced GA figure depends on the gap between the limitations of the 320×8 problem. As shown in *Fig. 15*, it can be observed that the IS algorithm optimizes the response at each stage of the execution. This experiment was conducted in 8 × 100 size for 20 optimization stages by all the algorithms.

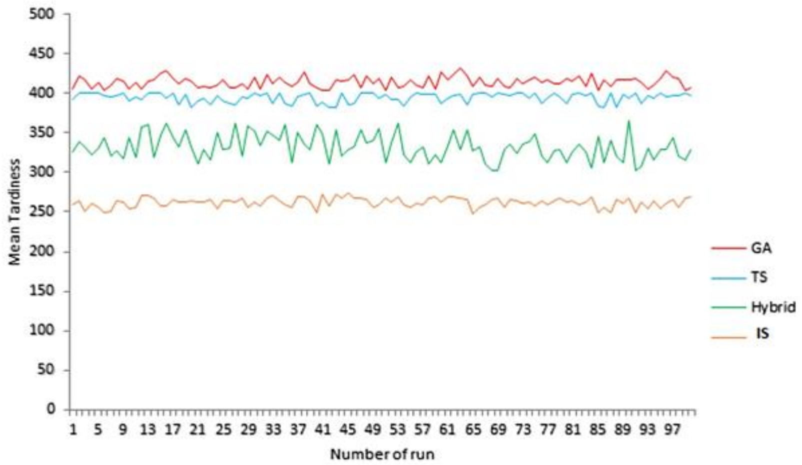

Fig. 12. The best solution of algorithms in the size of 8×100 in 100 consecutive samples.

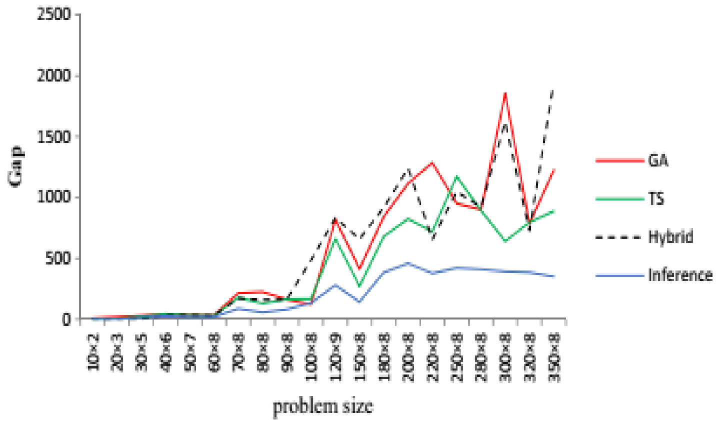

Fig. 13. The smallest degree of the obtained gap in 100 runs.

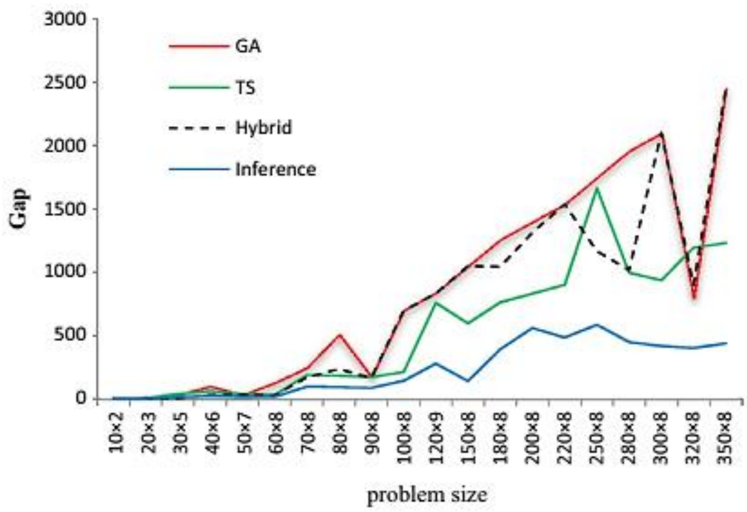

Fig. 14. The degree of the gap of the best-obtained solution in 100 runs.

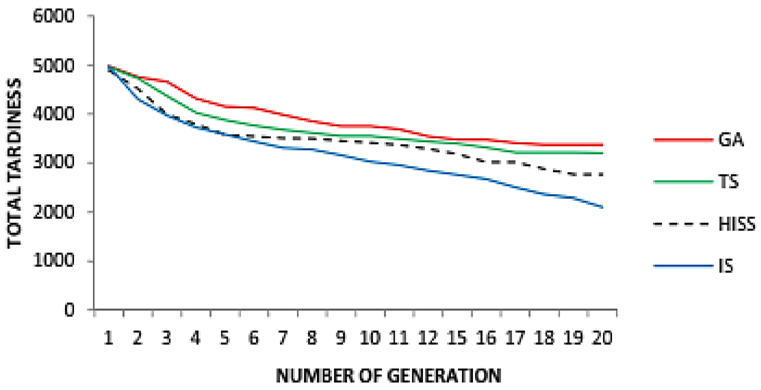

Fig. 15. Comparison of different algorithms during 20 stages.

The amount of time taken (in seconds) to reach the target in each episode is shown in *Fig. 16*.

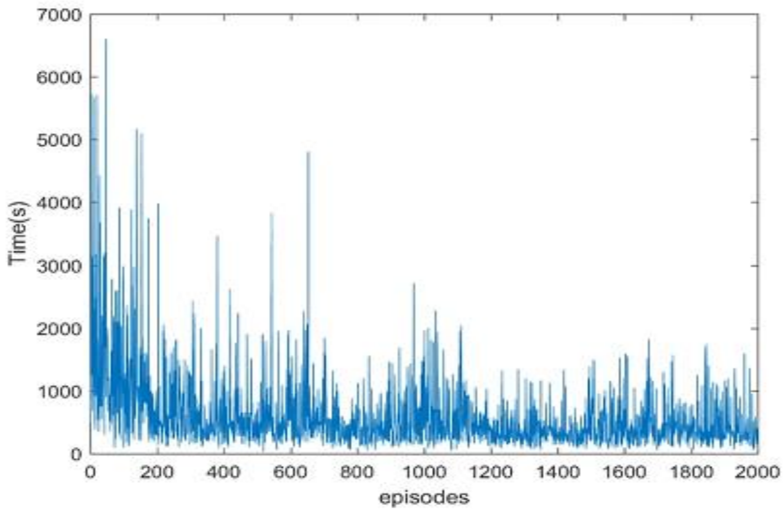

Fig. 16. Results of the proposed hybrid algorithm for 2000 episodes.

Simulation results show that the proposed scheme gives better results than other schemes. Indeed, due to the population production and the set of responses in each generation in the GA, responses are produced based on the size of the population. Since the structure of the IS algorithm follows human-like knowledge, it has higher performance and accuracy than other schemes. Hence, it can be argued that the proposed scheme has remarkable optimization and improves the execution speed. Indeed, this can be attributed to the presence of inference trees and knowledge rules, which lead to the optimization of responses and concentration on accurate scheduling. Firstly, the application of AGVS integrates a variety of advanced technologies into the electricity meter verification system, which brings great economic and social benefits by enhancing verification efficiency and reducing total labor costs.

It seems necessary for board management to raise their awareness of the efficiency of AVG in the long term when developing the business case. They see the benefits of AGV and operation costs benefits, so they allow smart AGV to be an integral part of every operation. Secondly, it is agreed that the implications of new technology in operation also bring challenges for the workforce and the management boards. So, they consider building human strategies for flexible change and adaptability with high customer service.

To sum up, application applications and new technology such as AGV have brought a lot of advantages. At the moment, it is hard to confirm that using AGV is one of the best solutions for a firm's operations in terms of cost. Driverless forklifts will be an integral part of the firm's operations in the near future.

5 | Conclusion

The present study attempted to propose a new approach to the regional coverage of machines on the production line to address the routing problem of AGVs. The problem modeling was relatively complex, considering the transportation costs and breakpoints. In comparison, the problem takes more time to be solved, but it has advantages such as minimizing the transfer costs and the number of breakpoints. The optimal route obtained from the model significantly decreases the costs associated with the AGV route as well as the service time of each AGV.

The results showed that the optimal solution to the problem was a loop, in which the AGV started giving service from one point and returned to the same starting point (no starting point was considered for the model since the model solution gives the optimal path and any point on the optimal route can be considered as the starting point) to firstly minimize the transfer costs of moving the AGV from one point to another and secondly to reduce the number of breakpoints in the coverage of all machines (Nash equilibrium).

The results also indicated that the final solution of the model was strongly dependent on the parameters of the model, and it was very sensitive to them. The proposed model of this paper is additionally applicable to alternative cases in which additional machines and AGVs are required to be used. The main contributions of this paper are summarized as follows: 1) the transfer costs and breakpoints are minimized so that the total travel distance of AGV and the objective value are reduced, 2) the tasks can be delivered in a shorter period of time. As a result, production costs are reduced, and production efficiency and productivity are improved, 3) the optimal area coverage model proposed in this paper can be used in other manufacturing enterprises, and 4) pure-strategy Nash equilibrium for the non-cooperative game always exists, and Nash equilibrium holds if and only if at least one AGV takes its dominant strategy. It is also worthwhile to develop a more efficient model considering the advantages and shortcomings of the present one. Further studies can pave the way for more development in this area. The optimal solution to the cooperative game must be in the Nash equilibrium solution set. The arrangement and number of machines are also taken into account. Considering the variety of AGVs, the possibility of applying multiple AGVs or increasing the number of machines in the production line, as well as the diversity of arrangement, routing, and scheduling of machines, further studies can be carried out which drastically change modeling and the optimal solution to the problem in general and even change the solution time of the model.

In the case of applying multiple AGVs in manufacturing systems, the problem of scheduling and routing several AGVs with the proposed model can be studied in further studies. AGV routing for such problems can be studied further by those interested in this field. Future work will include this idea and will extend the current approach to a game theory-based model with incomplete information using quantum response equilibrium. This will make it possible to address scenarios in which the autonomous vehicle is not capable of obtaining all the required information from the vehicles in the target lane. In addition, the reaction time will be considered in the payoff functions, and the proposed model will be generalized such that it can be applied to both not-crowded and crowded urban scenarios. Future research could also investigate the development of more efficient algorithms with the guarantee of finding equilibrium. One of the main limitations is the flexibility of the players (parties). To remain, the flexibility of a party (player) is defined by the radius of the maneuvering space of the party, which consists of all acceptable positions. The maneuvering spaces are defined as an m-multidimensional Euclidean policy space. The flexibility of the players was selected for testing the formulated hypotheses.

Author Contributions

Conceptualization, Mansour, Abedian and AmirHossein, Karimpour; Methodology AmirHossein, Karimpour, Software, Mansour, Abedian and AmirHossein, Karimpour; Validation, Mansour, Abedian, AmirHossein, Karimpour, and Atefeh, Amindoust; Resources, and Atefeh, Amindoust; Writing-reviewing

and editing Mansour, Abedian and AmirHossein, Karimpour; All authors have read and agreed to the published version of the manuscript.

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Data Availability

All data generated or analyzed during this study are included in this article.

Conflicts of Interest

The authors have no conflict of interest to disclose.

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